ESTIMATION OF TIME OF CONCENTRATION USING TRIANGULATED IRREGULAR NETWORK METHOD

by

EWE TEIK TSIA

Thesis submitted in fulfilment of the requirements
for the Degree of
Master of Science

OCTORBER 2015

ACKNOWLEDGEMENTS

First of all, I wish to express my gratitude to my supervisor, Dr. Lau Tze Liang and co-supervisor, Professor Dr. Nor Azazi Bin Zakaria for their guidance and advice throughout my thesis study.

Secondly, I would like to extend my appreciation to MES Innovation Sdn. Bhd. and its management in their financial support and help in the software development. I might not go this far without them.

I would like to thank the officers and technical staffs in River Engineering and Urban Drainage Research Centre (REDAC), Universiti Sains Malaysia; and Civil Engineering School (PPKA), Universiti Sains Malaysia for their helps, especially Mr. Mohamad Firdaus Talib and Mr. Mohd Sufian Osman. Their helps are deeply appreciated.

Besides, I would like dedicate my regards to my friends for giving me their generous helps and supports especially my senior, Engr. Leow Cheng Siang and my friend Ar. Yeoh Chen Lim.

Lastly and most importantly, I would like to give my deepest thanks to my late mother for her undaunted patience and endless support to me. Her love will always be with me forevermore. Also to my family for their encouragement in my pursue of this Master degree. Without their great support, this thesis would be impossible.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF SYMBOLS

Symbol	Definition
T_r	Average Recurrence Interval (year)
P	Annual Exceedance Probability (%)
t_c	Time of concentration (minute)
t_o	Overland sheet flow path time (minute)
t_d	Drainage flow time (minute)
t_g	Flow time for kerbed gutter (minute)
t_p	Travel time in the pipe (minute)
n	Manning's roughness
L_o	Overland sheet flow path (m)
L_d	The length from the L_o to streamline matching point to the catchment outlet (m)
S	Slope of overland surface (%)
V	The flow velocity (m/s)
t_{ci}	The travel time from Grid / TIN intersection to the outlet (minute)
t_{oi}	The travel time from Grid / TIN intersection to the streamline (minute)
t_{di}	The travel time from streamline matching point to the outlet (minute)

ANGGARAN MASA PENUMPUAN DENGAN MENGGUNAKAN KAEDAH RANGKAIAN PENYEGITIGA TIDAK TERATUR

ABSTRAK

Di Malaysia, Manual Saliran Mesra Alam (MSMA) telah mencadangkan dua kaedah pengiraan untuk mendapatkan luas antara isokron yang telah diamalkan secara meluas pada masa ini. Mereka adalah kaedah Grid dan kaedah Konvensional. Tetapi, kaedah-kaedah ini menimbulkan masalah yang tersendiri. Walaupun kaedah Grid adalah lebih terperinci dan tepat apabila dibandingkan dengan kaedah Konvensional, ia adalah amat membosankan dan memakan masa. Kaedah Konvensional sebaliknya adalah lebih mudah untuk digunakan. Tetapi, keputusannya tidak konsisten. Keputusannya adalah sangat subjektif kerana ia bergantung kepada pengalaman dan penilaian setiap pengguna. Justeru, kaedah pengiraan baru yang dikenali kaedah Rangkaian Penyegitiga Tidak Teratur (TIN) telah direka dan dibangunkan dalam kajian ini untuk meningkatkan pengiraan kaedah Masa-Luas. Kaedah ini adalah berasaskan komputer dan dengan itu algoritma kaedah TIN dibangunkan. Algoritma kaedah TIN telah dijelaskan dalam kajian ini. Satu tapak kajian telah dibina dan lapan set data hujan dikumpul. Semua hasil pengiraan daripada setiap kaedah disahkan dengan data tapak yang dikumpul untuk membandingkan ketepatannya. Siasatan ke atas kecekapan dan kebolehpercayaan kaedah-kaedah ini juga dijalankan dalam kajian ini. Perbandingan ini menunjukkan bahawa kaedah TIN mempunyai ketepatan yang lebih tinggi. Dalam perbandingan pekali korelasi antara kaedah yang ada, kaedah TIN mempunyai ketepatan purata 0.988, kaedah Grid mempunyai ketepatan purata 0.936 dan kaedah Konvensional mempunyai ketepatan purata 0.948. Apabila mengira peratus perbezaan mereka terhadap data yang dicerap, kaedah TIN mempunyai perbezaan purata 14.29%, kaedah Grid mempunyai perbezaan purata

25.67% dan kaedah konvensional mempunyai perbezaan purata 24.52%. Apabila menggunakan aliran puncak bagi perbezaan terhadap data yang diperhatikan, keputusan menunjukkan bahawa kaedah TIN mempunyai perbezaan purata 3.48%, kaedah Grid adalah 5.88% dan kaedah konvensional ialah 7.72%. Akhir sekali, dengan menggunakan jumlah isipadu aliran, kaedah TIN hanya mempunyai 0.19% perbezaan dengan data yang diperhati, kaedah Grid mempunyai 0.43% dan kaedah Konvensional mempunyai perbezaan sebanyak 4.80%. Kaedah TIN menunjukkan ketepatan dan kebolehpercayaan yang lebih tinggi berbanding dengan dua kaedah yang lain. Selain itu, kajian ini juga menunjukkan bahawa algoritma kaedah TIN yang baru dibangunkan adalah lebih mudah untuk digunakan, memakan masa yang kurang dan lebih dipercayai.

ESTIMATION OF TIME OF CONCENTRATION USING TRIANGULATED IRREGULAR NETWORK METHOD

ABSTRACT

In Malaysia, Manual Saliran Mesra Alam (MSMA) has proposed two calculation methods to obtain areas between the isochrones that have been widely practiced at the moment. They are Grid method and Conventional method. However, these methods pose certain problems of their own. Although the Grid method is more detail and accurate when compared to the Conventional method, but that is extremely tedious and time consuming. Conventional method on the other hand is simpler to use. But, the results are not consistent. The results are very subjective because it depends on each user's experience and judgement. Therefore, a new calculation method named Triangulated Irregular Network (TIN) method has been designed and developed in this research to improve the Time-Area method calculation. This method is computer based and thus the algorithm of TIN method was developed. The algorithm of the TIN method is explained in this research. A study site was constructed and eight sets of rainfall data were collected. All the results from each calculation method were verified with the collected site data to compare their accuracy. Investigation upon their efficiency and reliability were also presented in this research. The comparison showed that TIN method has higher accuracy. In the correlation coefficient comparison among the methods, TIN method has average accuracy of 0.988, Grid method has average accuracy of 0.936 and Conventional method has average accuracy of 0.948. When calculating their difference against the observed data in percentage, TIN method has average difference of 14.29%, Grid method has average difference of 25.67% and Conventional method has average difference of 24.52%. When using the peak flow

comparison for the difference against the observed data, the results shows that TIN method has average difference of 3.48%, Grid method has average difference of 5.88% and Conventional method has average difference of 7.72%. Lastly, the methods were compared using the total flow volume. It was demonstrated that the TIN method has different of 0.19%, Grid method has different of 0.43% and Conventional method has different of 4.80% when compared to the observed data. The TIN method has the highest accuracy and reliability among the three methods. Besides, this research also showed that the newly developed TIN method algorithm is easier to use, less time consuming and more reliable.

CHAPTER 1

INTRODUCTION

1.1 Research Background

Human beings have strived to survive on the surface of the Earth while learning to cope with its terrain. With their specialists, civil engineers are able to analysis, design and construct buildings and infrastructures on the Earth terrain. Throughout the years, civil engineers have tried every mean to represent phenomena and the characteristic of a terrain through mapping. To date, modern map generators employ a well-designed symbol system and well-established basis to represent three major characteristics of a terrain (Li et al., 2005). They are:

a. measurability warranted by mathematical rules;

b. overview provided by generalization; and

c. intuition by symbolization.

In modern mapping, Triangulated Irregular Network (TIN) meshing is a map generators that include all the above-mentioned characteristics and most importantly, it offers a high accuracy in the terrain re-sampling (terrain modelling) process. After the new terrain has been generated, the travel time for each TIN intersection can be obtained by linear interpolation. With this set of travel time data, the area of isochrones can be generated for Time-area method calculation.

1.2 Time of Concentration

When precipitation reaches the Earth, some will be evaporated, some will be retained by vegetation, some will infiltrated into the ground and some will become the surface runoff (Figure 1.1). The surface runoff is an important component of the hydrologic response of a catchment because the period of time where the runoff travels to the downstream outlet formulates the time of concentration.

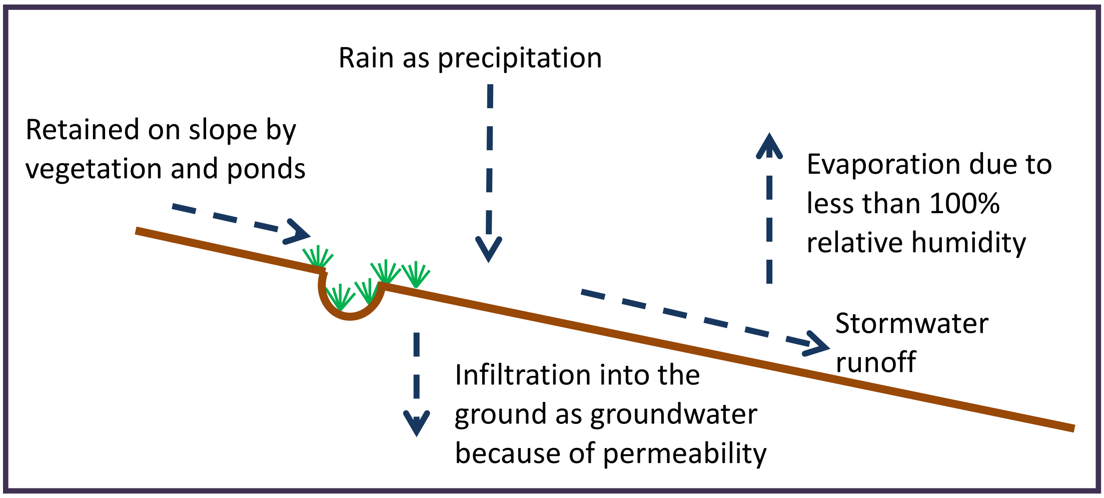

Figure 1.1: Rainfall phenomena

Runoff from precipitation moves through catchment in three ways. They are sheet flow, shallow concentrated flow and stream flow (Baird et al., 2002). According to Baird et al. (2002), sheet flow is defined as the flow with length not more than 300 feet. While shallow flow is started at the point where sheet flow ends. Lastly, the stream flow starts when shallow flow enters a well-defined channel. The flow travel time from the most hydraulically remote point in the contributing catchment area to the point under study is defined as the time of concentration, t_c (McCuen et al., 1984; JPS, 2001; Baird et al., 2002). The time of concentration can also be defined as the time between the centre of rainfall amount excess the earth and the inflection point on the recession of the direct runoff hydrograph. Hence, the time different between the end of rainfall excess and the inflection point can be computed by time of concentration (McCuen et al., 1984).

There are three major factors affecting the time of concentration (TR-55, 1986):

a. surface roughness;
b. channel shape and flow patterns; and
c. surface slope.

The Manning's roughness coefficients are always valid to apply in assuming the catchment characteristics (McCuen et al., 1984). There are different methods in calculating both natural catchment and developed catchment. For the natural catchment, the time of concentration is using Bransby-Williams' Equation, which the time for overland flow and stream flow are included. However, for the developed catchment, the time of concentration is the summation of the time of overland flow and the time of travel in the stormwater conveyance system such as drainage systems. In a large study area, time of concentration should be estimated on the basis of locally observed data (JPS, 2000). If the time of concentration is too long, it will create a low peak discharge (under-design) which might result an unsafe condition. Therefore, engineers will limit the length of the sheet flow portion of the total flow path (McCuen et al., 1995).

There are two types of surface runoff channel, i.e. overland flow and well defined conveyor system. Overland flow can be occurred on both unpaved surfaces (such as grasses) and paved surfaces (such as concrete surface). The Friend's Formula is used to estimate overland sheet flow times, t_o with the overland sheet flow path length is measured by designer and the value of the surface is given (JPS, 2000). The drainage flow time, t_d is defined as the drain length divided by the average pipe velocity which calculated by using Manning's Equation.

The time of concentration is a variable figure which affects the catchment runoff. A research carried out by Wong (2008) found that channels with longer travel time and large detention storage will produce a smaller outlet discharge. Based on this research, Wong concluded that the channel shape can be used to manage the catchment runoff in order to control the downstream ponding condition. Beside the travel time, the increase in level of discretization will increase the value of time of concentration as well (Pavlovic et al., 2008). This can potentially decrease the outlet discharge.

In the physical point of view, the time of concentration is the time needed for the runoff to travel from the most hydraulically distant point to the catchment outlet. This point is not necessary the point with the longest flow distance, but it is a point with the longest travel time. This point is very depending on the slope and the character of the catchment or the flow path. However in the hydrograph analysis, the time of concentration is the time from the end of excess rainfall to the point of inflection where the recession of the curve begins (Woodward et al., 2010). Other than that, in Rational Method, the time of concentration is equal to the rainfall duration when determining design rainfall intensity (Liang & Melching, 2012).

1.3 Problem Statements

To date, there are two methods to calculate the area of isochrones, i.e. Conventional method and Grid method. Although the Conventional method has been widely practiced by local engineers, this method is still remained with uncertainty. This method always faces a problem on how to accurately define the area of isochrones from the time of concentration. There could be a number of possibile ways to consider in determining the time of concentration to calculate the area of isochrones. In order to calculate the time of concentration, the flow path along which the longest travel time is likely to occur, has to be identified. Often, this process could be very time consuming and tedious. The judgement on how or should the area of isochrones be defined by this methods is too subjective. It is always judged by the experience. The judgement could be very subjective. Therefore the accuracy is relatively low. The Conventional method is time consuming and tedious to be used.

Grid method on the other hand provides a better guide and better precision. It could accurately define the time of concentration. When a set of grid is placed on a site, every grid intersection will be defined by the interpolation of the adjacent terrain elevation points. These points are then collected and re-sampling to calculate the travel time and area of isochrones. However during the process of re-sampling, the closest points are selected manually. This selection of the interpolation could be subjective. This re-sampling process will nonetheless corrupt or downgrade the accuracy.

An example will explain further the Grid method conundrum. Figure 1.2 below shows a part of topography with 1m contour line. A set of grid of 1m spacing is then placed on top of the topography as shown in Figure 1.3. Figure 1.4 shows that in order to calculate the time of concentration, the geometrical characteristic of the interpolation is required. Hence the value of the z-coordinate value is then assumed. Once the z-coordinates are obtained, the time of concentration could then be calculated, as shown in Figure 1.5. Then, the area of isochrones could be generated as shown in Figure 1.6. Table 1.1 shows a tabulation of the area between the isochrones.

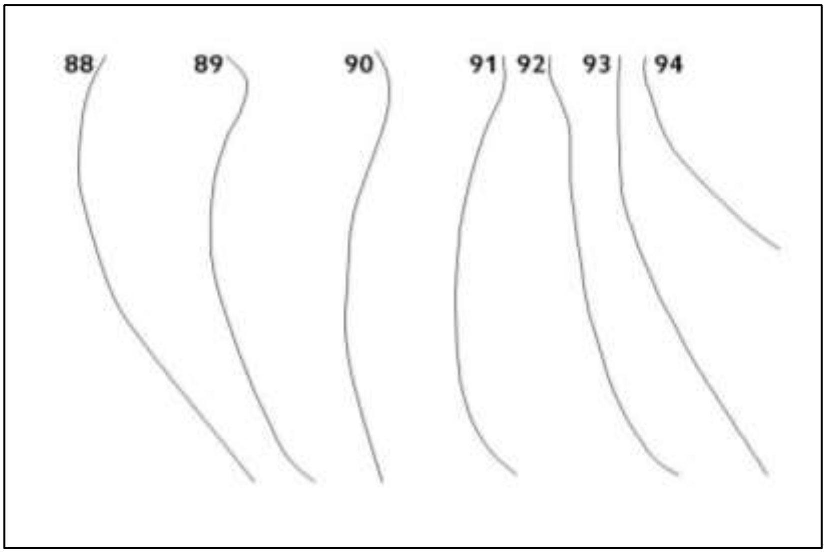

Figure 1.2: Topography with 1m contour line

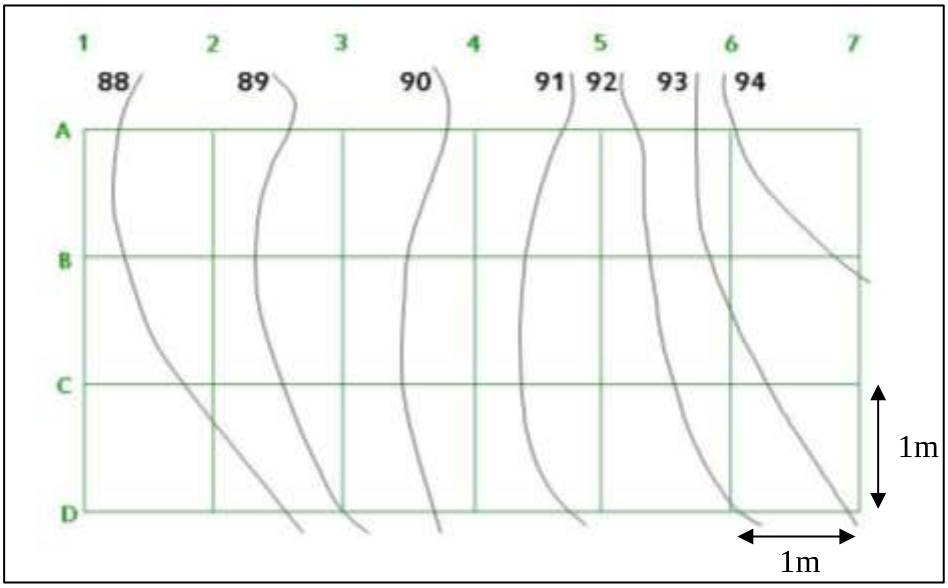

Figure 1.3: Superimpose of grid and contour line